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(54) Hyperthermia applicator

(57) An ultrasound (or microwave, I.R., U.V. or optical) hyperthermia applicator comprises a plurality of transducers which can be operated in different grouping modes so that the applicator is effectively provided with a variable number of elements transmitting coherent beams, such element comprising one or more transducers. The coherent beams from these elements are focused for incoherent superposition in the target volume according to a spiral or multi-spiral focusing scheme. Such an applicator is capable of uniformly heating without scanning a limited part of human body.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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FIG. 1

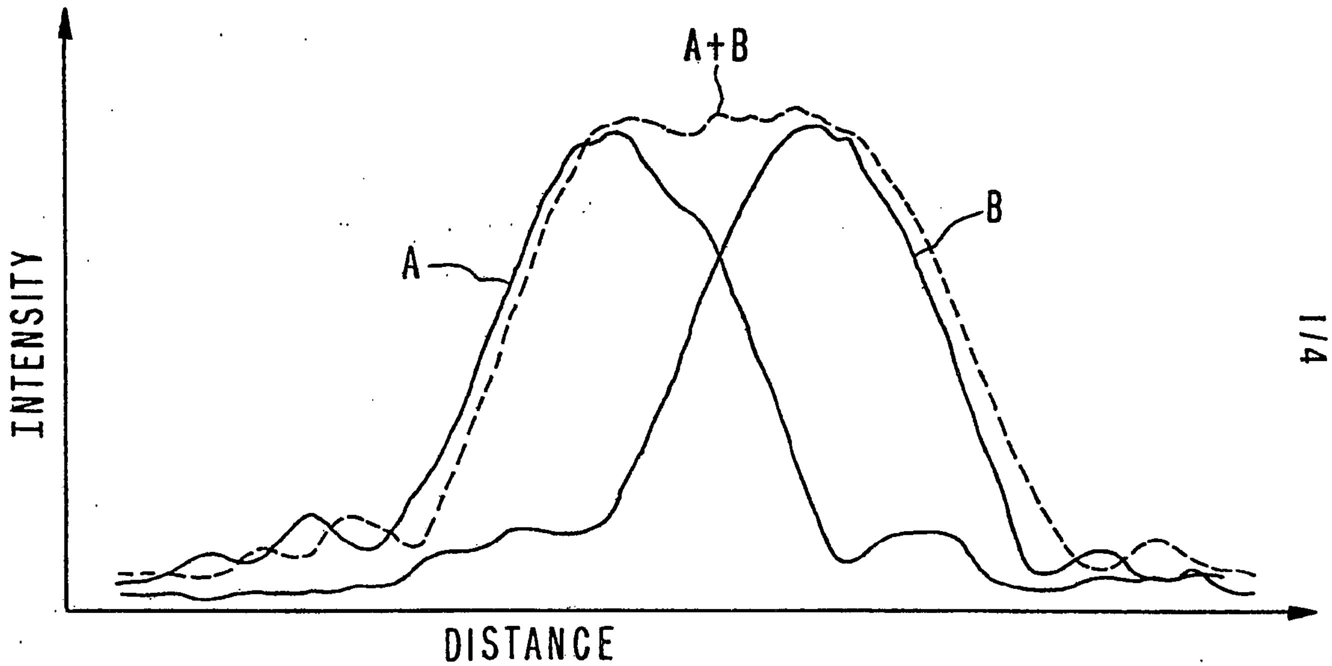


FIG.2

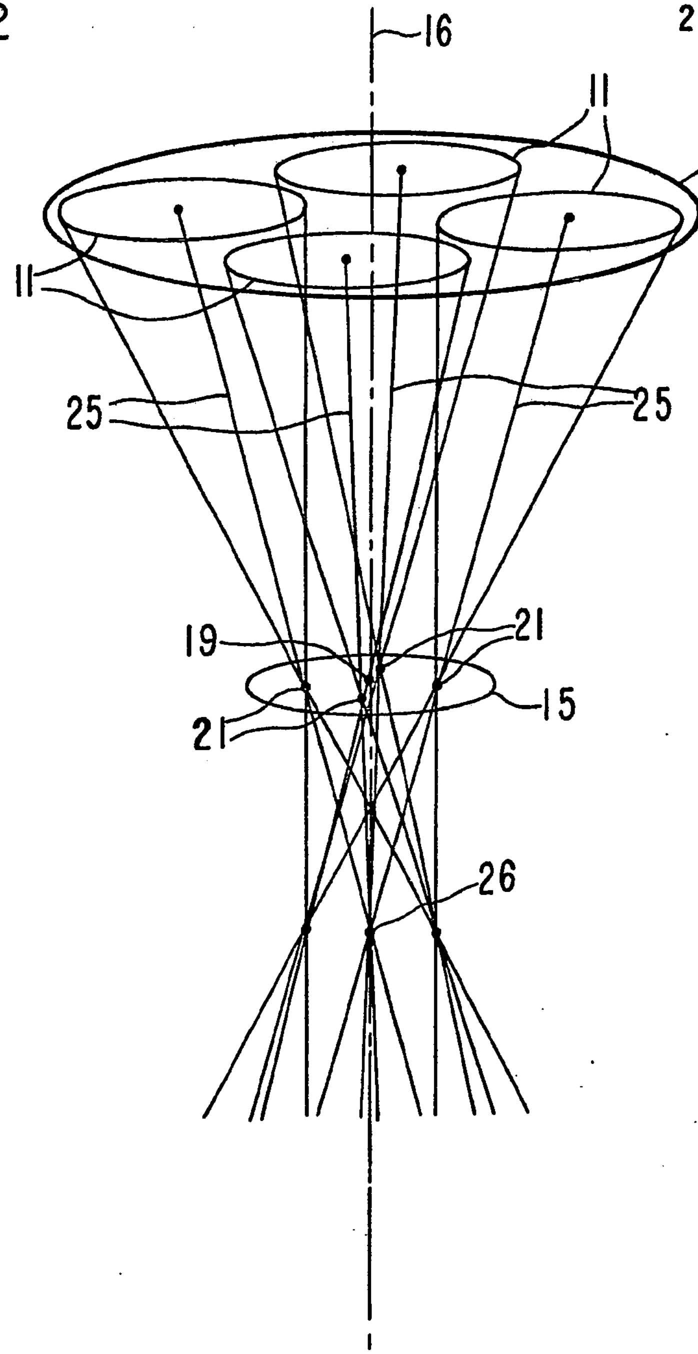


FIG.3

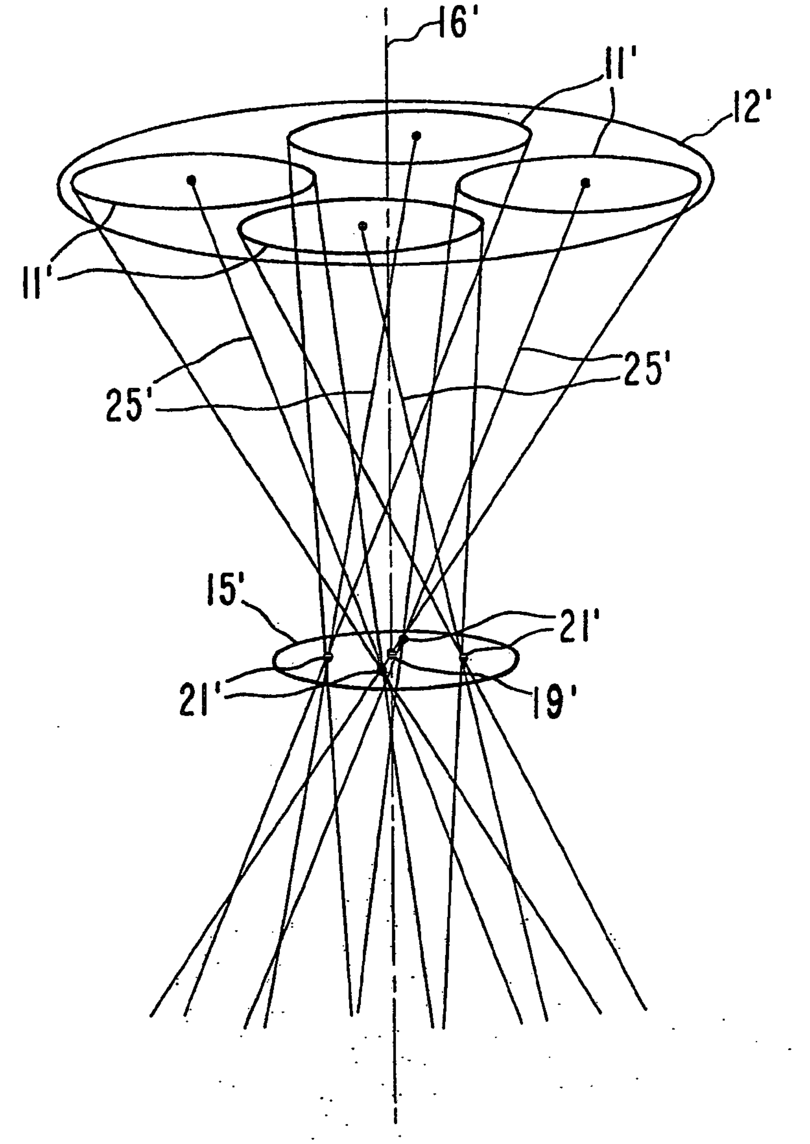


FIG.4a

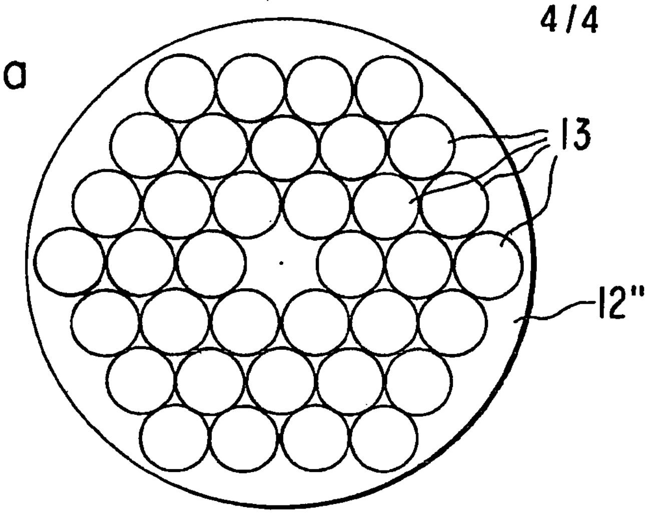


FIG.4b

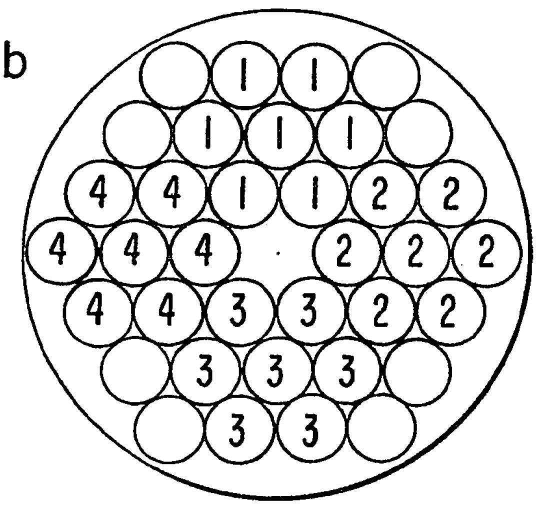
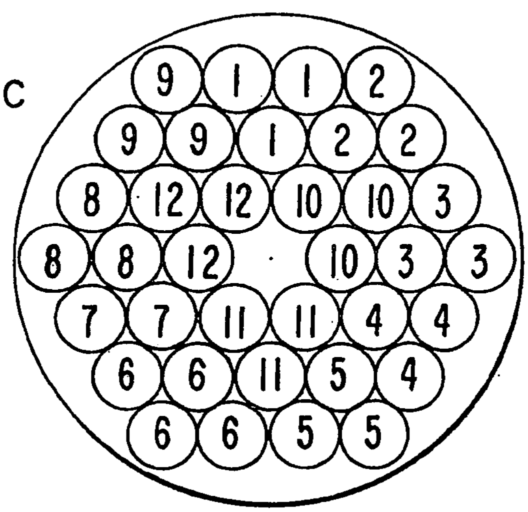


FIG.4c



SPECIFICATION

Ultrasound hyperthermia applicator with variable coherence by multi-spiral focusing

Background of the Invention

This invention relates to an apparatus for heating limited parts of a human body and more particularly to an ultrasound hyperthermia applicator capable of uniformly heating relatively large volumes locally without scanning.

Hyperthermia is a name which has come to mean high temperature in humans induced with therapeutic intent. Its application to cancer therapy is based on the discovery that malignant cells are generally more sensitive to heat than are normal cells. Physical techniques for hyperthermia include metabolic heat containment, heating by radio frequency or microwave energy absorption, conduction through the skin such as by a hot water bath, and perfusion of externally heated blood, heated intravenous fluids and anesthetic gases, but ultrasound is well known to offer advantages in that it has good penetration in tissue and that ultrasound heating can be focused and localized. The latter characteristic is particularly important because serious damage to healthy tissue and skin in the surrounding region must be avoided. For a given fixed frequency of ultrasound, however, the focal volume size for a single coherent focused transducer cannot be changed so that the treatment of a volume larger than the inherent focal size has previously been done by scanning, but scanning results in a high peak to average power ratio, and also introduces the complex problem of rapidly and accurately scanning the region to be heated.

Summary of the Invention

It is therefore an object of the present invention to provide an apparatus for heating a tissue volume deep within a patient without the necessity of scanning.

It is another object of the present invention to provide an ultrasound hyperthermia applicator capable of generating a variety of heating patterns by selection of frequency and the effective diameter and focal length of the individual coherent transmitter elements.

Brief Description of the Drawings

FIG. 1 shows qualitatively how an incoherent superposition of two individually coherent and individually focused beams can produce the effect of uniformly heating an extended region.

FIG. 2 shows schematically how an incoherent array of individually coherent beams individually focused on a target plane can have a point of maximum heat intensity some distance away from the target plane.

FIG. 3 shows schematically the spiral focusing method embodying the present invention according to which an incoherent superposition of individually coherent beams individually focused on a target plane does not result in any undesired points of increased heat intensity outside the target volume.

FIG. 4 shows examples of how individual transducers can be arranged on a plane so that they can be driven according to various grouping schemes.

Detailed Description of the Invention

Stated briefly, the basic principle upon which the present invention relies is that uniform heating becomes possible by incoherent superposition of two coherent ultrasound beams in the far field. Any coherent ultrasound beam in the far field has a transverse intensity profile as shown by Curve A of Fig. 1. If another such coherent beam shown by Curve B is incoherently superposed, the resultant profile is shown by Curve (A + B) which rises and falls as rapidly as Curves A and B, but remains relatively constant over an extended distance. Thus, it is theoretically possible to obtain almost any resultant pattern of power level by superposition of many incoherent beams in this manner. This must be done, however, so that their beam center lines will not intersect outside the treatment volume because such intersection point will represent a position of maximum heat intensity. Referring now to Fig. 2 which schematically shows a typical example whereby such point of maximum intensity occurs outside the treatment volume, four transmitter elements 11, each having a finite effective beam diameter shown by a circle, are placed in an approximately square formation on transducer plane 12 some distance away from and directly facing the target area 15, that is, the line 16 through the center of the square formation and normal to transducer plane 12 will also pass through the center 19 of and is perpendicular to the plane of target area 15. Four focal points 21 are selected on target area 15 in an approximately square formation so that they are not only at a same distance from line 16, but also at the same azimuthal angles with respect to line 16 as the transmitter elements 11.

Each of the transmitter elements 11 is a source of coherent beams and is focused at the nearest of the focal points 21, or that focal point which is at the same azimuthal angle as the transmitter element itself with respect to line 16. This focusing scheme is illustrated in Fig. 2 by means of representative beams from each element 11 including beam center line 25. The four transmitter elements 11 are focused incoherently with respect to one another, but this scheme for incoherent superposition of individually coherent beams is not satisfactory because the four beam center lines 25 intersect one another on line 16 at point 26. This will turn out to be a point of maximum heat intensity and it is likely that this point may lie outside the target volume.

The present invention is addressed to the problem of eliminating this difficulty. Referring now to Fig. 3 illustrating the spiral focusing scheme of the present invention by a simple example, components corresponding to those of Fig. 2 are given like reference numerals. Four transmitter elements 11′ are positioned opposite

to, and four focal points 21' are selected on target area 15' in an identical manner as in Fig. 2, but each of the transmitter elements 11' is focused not on the nearest of the focal points 21' (i.e., the one at the same azimuthal angle with respect to the center line 16' as the transmitter element), but on the one displaced therefrom by 90° counterclockwise (seen from above). As a result, the four beam center lines 25' are now in a spiral-like formation and hence are prevented from intersecting one another. In fact, Fig. 3 indicates that the position of maximum intensity is spread over the target area itself.

As one of the preferred embodiments of the present invention based on the principle described above, Fig. 4(a) shows 36 transducer elements 13 which are brazed to base plate 12" into a regular hexagonal shape in such a way that the lines connecting the centers of the mutually adjacent circles, each representing the effective diameter of the beams from a transducer element, form a closely packed matrix of equilateral triangles. RF power at fundamental or high resonant mode frequencies, dependent on the depths of treatment, can be matched to each transducer element via a multitrap toroidal impedance transformer (not shown). Each of elements 13 may be individually focused, or alternatively a group of several adjacent transducers can be to act as a coherent transmitter element of a larger effective diameter. In Figs. 4(b) and (c), two such examples are shown wherein transducers marked by the same numeral are to form a single transmitting element (e.g., 11 of Fig. 2) while transducers marked by different numerals are emitters of beams for incoherent superposition. Fig. 4(b) shows a mode in which 8 of the 36 available transducers are not activated and the remaining transducers are divided into 4 groups (transmitting elements) of 7 (transducers) each, approximating the situation shown in Fig. 3. Fig. 4(c) shows another example of grouping whereby the 36 transducers are divided into 12 groups (transmitting elements) of 3 (transducers) each.

The beams from each transmitter element thus formed by a single transducer (as in Fig. 4(a)) or a group of transducers (as in Figs. 4(b) and (c)), are focused at a selected target point according to a scheme as illustrated in Fig. 3.

According to the spiral focusing scheme which embodies the present invention, a target area (like 15' of Fig. 3) with a finite effective diameter is selected and the base plate 12" is positioned directly opposite to it some distance away so that a central line normal to both the base plate and the target area is definable (as line 16' of Fig. 3). Beams from each transmitter element are focused at a particular target point on the target plane in such a way that (1) these target points describe on the target plane a pattern which is similar (in the sense of the word used in geometry), but rotated around the central normal line by a fixed angle with respect to the pattern formed on the plane of base plate by the centers of the effective beam diameters of the transmitter elements and that (2) each beam center line (like 25' of Fig. 3) connects corresponding points of the two similar patterns. Stated in another way, beams from a transmitter element whose center is at distance R from and at azimuthal angle A (with respect to a fixed reference direction) around the central normal line defined above are focused on the target plane at a point at distance rR from and at azimuthal angle A + Z where r is a predetermined multiplicative factor less than unity and Z is a fixed angle (of spiral rotation).

As a result of the focusing scheme described above, the beam center lines assume a spiral-like formation around the central normal line as shown in Fig. 3. If a large number of transmitter elements are used so that their distances to the central normal line are not uniform, the beam center lines may assume a double or multi-spiral formation. The preferred angle of rotation also changes according to the distribution of the transmitter element because it should not be so small that points of substantially enhanced heating may appear outside the target volume, while it should not be so large that beams from adjacent transmitter elements may intersect each other. In the case of four transmitter elements installed in a substantially square formation as shown in Fig. 2, 3 or 4(b), the angle of spiral rotation (i.e., Z) should be in the range of about 30°—150° and preferably nearly equal to 90°.

Focusing of the beams from individual elements according to any of the above-described schemes is accomplished by placing an acoustic lens (not shown) parallel to the transducer plane 12 and in front of the transducers 11. The lens is easily removable and exchangeable with another of different type so that different focusing characteristics can be obtained. A patient interface (not shown), or the surface through which the applicator may come into contact with the patient, is made of thin rubber. In order to prevent overheating of the applicator components such as the transducers, the acoustic lens and the patient interface, a system of passages (not shown) is provided for circulating a liquid such as water. The liquid can circulate both through passages between the lens and the transducers and those between the front surface (facing the patient) of the lens and the patient interface for efficient cooling.

The present invention has been described above in terms of only a few particular embodiments. The above description, however, is to be considered as illustrative rather than limiting. For example, the beams need not be ultrasound waves. The technique of the present invention is equally applicable to apparatus using transverse waves such as microwaves and infrared, optical or ultraviolet waves. The total number of transducers to be affixed to the base plate can be varied freely. Since the basic principle is to employ an incoherent array of individually coherent and individually focused beams, any number of such individual sources of coherent beam can be used

in an applicator of the present invention. They may be affixed to their predetermined positioned by any method. Any number of individual transducers may be grouped together to form a transmitter element of the type shown in Fig. 3 (not necessarily 7 as in Fig. 4(b) or 3 as in Fig. 4(c)), and hence the size and pattern of such elements can also be varied. Any method known in the arts may be used to drive transducers within each transmitter element to emit coherent beams. The pattern according to which the centers of transmitter elements are distributed on the transducer plane need not be exactly identical to that of their foci as long as the plane of maximum heat intensity is formed substantially close to the plane of their foci for the purpose of treatment. Focusing of the beams and cooling of the device can be accomplished by any method. Passages for circulating a liquid may be provided according to any reasonable design. The scope of the invention is limited only by the following claims.

CLAIMS

1. A device for uniformly irradiating a target volume by an incoherent array of individually coherent beams which are individually focused, said device comprising a plurality of beam transmitter elements having finite effective beam diameters and positioned at predetermined source locations, each of said transmitter elements being adapted to transmit coherent beams focused at a target point, the beam center lines of said transmitter elements not mutually intersecting outside said target volume.

2. The device of claim 1 wherein said beams are ultrasound beams and each of said transmitter elements comprises one or more transducers.

3. The device of claim 1 wherein all said source locations lie on a transmitter plane and said target points lie on a target plane which is parallel to said transmitter plane.

4. The device of claim 3 wherein the geometrical pattern of said source locations on said transmitter plane is similar to the pattern of said target point on said target plane, said pattern of source locations being in a rotated relationship with said pattern of target points around an axis perpendicular to said transmitter plane by a predetermined angle.

5. The device of claim 4 wherein said angle is in the range of 30° to 150°.

6. The device of claim 1 further comprising a plurality of transducers which can be operated to transmit coherent beams both individually and in groups.

7. The device of claim 6 wherein said target volume is larger than the inherent focal volume size of each of said transducers.

8. The device of claim 1 wherein said beam center lines do not intersect one another.

9. The device of claim 6 further comprising an acoustic lens and a means for circulating liquid for cooling said device.

10. The device of claim 6 wherein the number of said transmitter elements and said effective diameters are variable by operating said transducers in different grouping modes.

11. The device of claim 6 wherein said lens is easily removable and replaceable for another lens with a different focusing characteristic.

12. A device for transmitting individually coherent and mutually incoherent beams from a variable number of transmitting sources having variable effective diameters, said device comprising a large number of transmitters at fixed relative locations and a means for variably dividing said transmitters into groups and causing transmission of beams from said transmitters in such a way that the beams from the same group are coherent and the beams from different groups are mutually incoherent.

13. A method of uniformly irradiating without scanning a target volume by an incoherent array of individually coherent beams which are individually focused, said method comprising the steps of transmitting a coherent beam having a finite effective diameter from each of a number of beam sources and focusing each of said coherent beams at one of said number of target points selected inside said volume, the center lines of said focused beams from different ones of said sources not intersecting outside said target volume.

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